Technical Note: A dynamic model to predict the composition of fat-free matter gains in cattle

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ABSTRACT: Composition of empty BW (EBW) was described in terms of ether-extractable lipid (FAT) and fat-free matter (FFM), and the terms dEBW, dFAT, and dFFM were used to represent daily gains in these components. The dFFM comprised protein, water, and ash, and a model was developed to predict the composition of dFFM. The conceptual approach used in model development was based on experimental data that showed as cattle grew from birth to maturity: 1) the water content of FFM decreased and the protein and ash content increased; 2) the protein content of FFM increased at a decreasing rate; and 3) the protein-to-ash ratio in the fat-free DM was approximately constant. These results suggest that the protein content of dFFM would be high at birth and decrease at a decreasing rate as the animal grows. The protein content of dFFM was predicted as a function of the fraction of dEBW that was dFFM, FAT content of EBW, and dFFM. A fixed protein-to-ash ratio of 4.1:1 was used to calculate the quantity of ash, and water was obtained as a residual. Growth and body composition of Hereford × Angus steers from birth to 500 kg BW were simulated with a previously published model using the experimental growth data as input, and the model under discussion was used to predict the composition of dFFM. Predicted response curves of the EBW components over the growth period were similar in shape to observed data. Predicted curvilinearity in response of protein weight against FFM weight for Hereford × Angus steers was similar to observed data. The standard error about the regression of predicted on observed protein weight was 1.87 kg, and the average bias of the model was to underpredict protein weight by 0.64%. Compared with using a constant value for the protein fraction of dFFM, the model provided more accurate predictions of dEBW in an independent evaluation data set.

Key Words: Body Composition, Cattle, Model, Protein

Introduction

The major change in the body composition of mammals that occurs with growth and development is an increase in the fat content. Murray (1919) and Moulton (1923) concluded that chemical composition can be determined when the fat content is known because the fat-free matter is of the same composition regardless of the degree of fatness. Therefore, the major effect of fattening on the concentration of water, protein, and ash in the whole empty BW is that of dilution. Murray (1922) showed that water content of the fat-free empty body decreases as animals increase in BW and that the protein-to-ash ratio in the fat-free DM was practically constant. These results indicate that it would be erroneous to assume constant composition of the fat-free empty body.

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Biological models that simulate animal growth predict nutrient retention in protein and ether-extractable lipid (**FAT**). These models calculate daily gains in fat-free matter (**FFM**) by dividing daily protein accretion by the fraction of protein in FFM, and empty BW gain is obtained as the sum of FAT and FFM. The value used for the fraction of protein in FFM matter plays a crucial role in these calculations, and in most cases, a constant value is assumed. Values of 0.22 and 0.24 for the fraction of protein in FFM would result in FFM gains of 345.5 and 316.7 kg, respectively, for a steer that gains 76 kg of protein between birth and slaughter, representing almost a 29-kg difference in predicted slaughter BW and suggesting a need for a more mechanistic approach to estimate the fraction of protein in FFM gain. The objectives of this study were to investigate compositional changes in FFM as animals grow and to develop a component model to predict the fraction of protein in FFM gain.
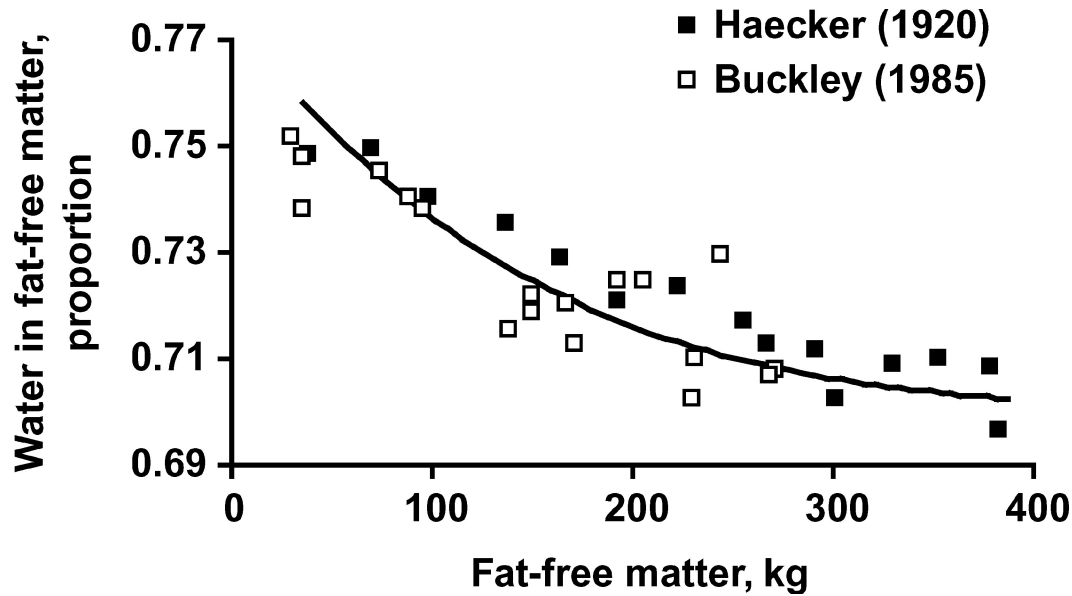
Materials and Methods

Life cycle compositional changes in FFM of cattle from experimental data published previously were used

Figure 1. Relationship between the fraction of water in empty body fat-free matter and empty body fat-free matter weight. Plotted data were obtained from published reports by Haecker (1920) and Buckley (1985). The curved line illustrates the nonlinearity in both sets of data.

to develop concepts for the formulation of a dynamic mathematical model to predict the fraction of protein in FFM gain. The term empty BW (**EBW**) is used to refer to the BW of the animal that excludes the weight of contents of the gastrointestinal tract. Major components of EBW are FAT and FFM. The FFM contains protein (**PRO**), water, and ash. Daily rates of change in these four components (EBW, FAT, FFM, and PRO) are prefixed with the letter "d" to signify a change in daily rate (e.g., dEBW). Daily changes in protein weight are modeled with the following equation:

$$dPRO/dt = (dPRO/dFFM) \times (dFFM/dt)$$

where dPRO/dt is the daily change in protein weight, dPRO/dFFM is the fraction of protein in dFFM, and dFFM/dt is the daily change in FFM weight. When dPRO/dt is known, dFFM/dt can be calculated as dPRO/dt multiplied by the reciprocal of dPRO/dFFM. The symbol λ will be used to represent dPRO/dFFM, and a mathematical model for λ will be developed.

Data from Haecker (1920) and Buckley (1985) in Figure 1 show that the fraction of water in FFM decreased curvilinearly with increases in FFM weight. The other components of FFM are protein and ash, and assuming that the ratio of protein to ash in the fat-free DM is constant (Reid et al., 1955), these data indicate that the fraction of protein in FFM would increase with increases in FFM. Growth is a result of increases in both FAT and FFM; hence, as an animal grows from birth to maturity, the fraction of protein in FFM also would increase with empty body fatness, as illustrated with data from Haecker (1920) and Buckley (1985) in Figure

2. These data indicate that at any point on the growth curve, any gain in FFM must include a greater fraction of protein than the fraction of protein in the FFM at that point on the growth curve (i.e., λ would increase with empty body fatness). The data also suggest that λ would increase at a decreasing rate with empty body fatness, and a candidate equation that would represent these responses in λ is shown below.

$$\lambda = 1 - 0.81 \times (1 - F^{\Theta}) \quad [1]$$

where F is FAT/EBW. The constant, 0.81, is used to represent the average nonprotein fraction of FFM of calves at birth (Ellenberger et al., 1950). If Θ is 1, and the average empty body fatness of calves at birth is 3.0%, this would result in a value of 0.2143 for λ at birth.

Using a constant value of 1 for Θ, Eq. [1] would become a straight line with an intercept of 0.19 and slope of 0.81, and λ would increase at a constant rate with increases in F. To make λ increase at a decreasing rate the value of Θ must be greater than 1, and this value must increase as F increases. A candidate function for Θ to satisfy these conditions is proposed:

$$\Theta = \phi \times e^{-dFFM/dEBW} \quad [2]$$

where ϕ is a parameter, and dFFM/dEBW is the fraction of dEBW that is FFM. As an animal grows from birth to maturity, gains in EBW include an increasing fraction of FAT and a decreasing fraction of FFM. These gains in FAT and FFM increase the value of F and decrease the value of dFFM/dEBW, resulting in an increasing value for Θ in Eq. [2]. At birth, the value of
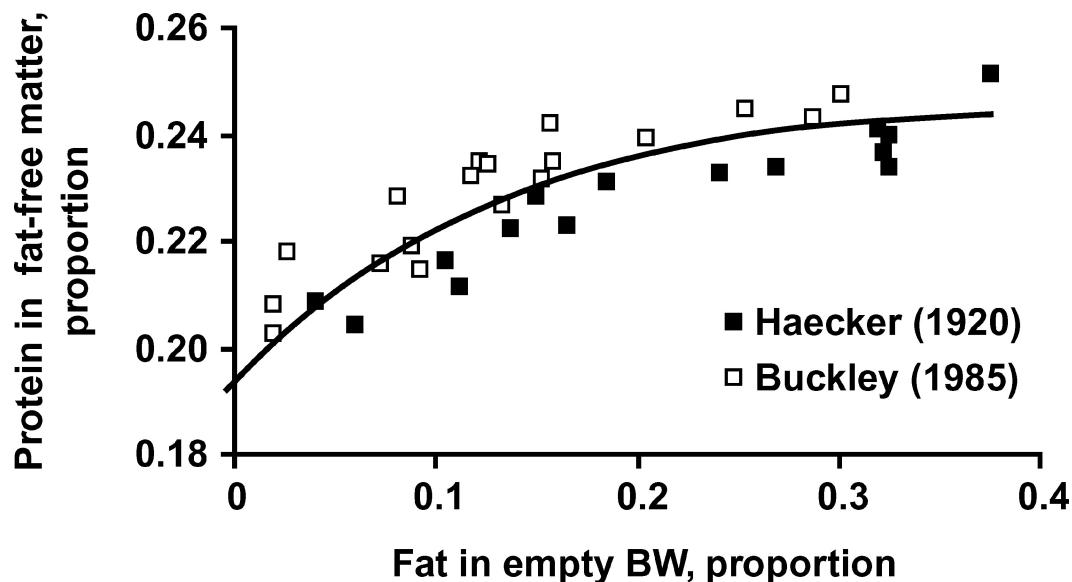
Figure 2. Relationship between fraction of protein in empty body fat-free matter and empty body fatness. Plotted data were obtained from published reports by Haecker (1920) and Buckley (1985). The curved line illustrates the nonlinearity in both sets of data.

dFFM/dEBW is approximately 0.91, and the exponential part of Eq. [2] would equate to 0.4; hence, for Θ to be greater than 1, the value of the parameter ϕ must be greater than 2.5.

The first derivative of λ with respect to F in Eq. [1] represents the change in λ with a change in F. This derivative is

$$d\lambda/dF = 0.81 \times F^{\Theta} \times \Theta \times (\ln[F] + 1/F) \qquad [3]$$

and the daily change in λ can be derived according to the chain rule for derivatives as follows:

$$d\lambda/dt = (d\lambda/dF) \times (dF/dt) \qquad [4]$$

The model for λ as formulated with Eq. [1] and [2] requires input that would be generated daily from most biological simulation models of animal growth. The model of Williams and Jenkins (2003a,b) predicts
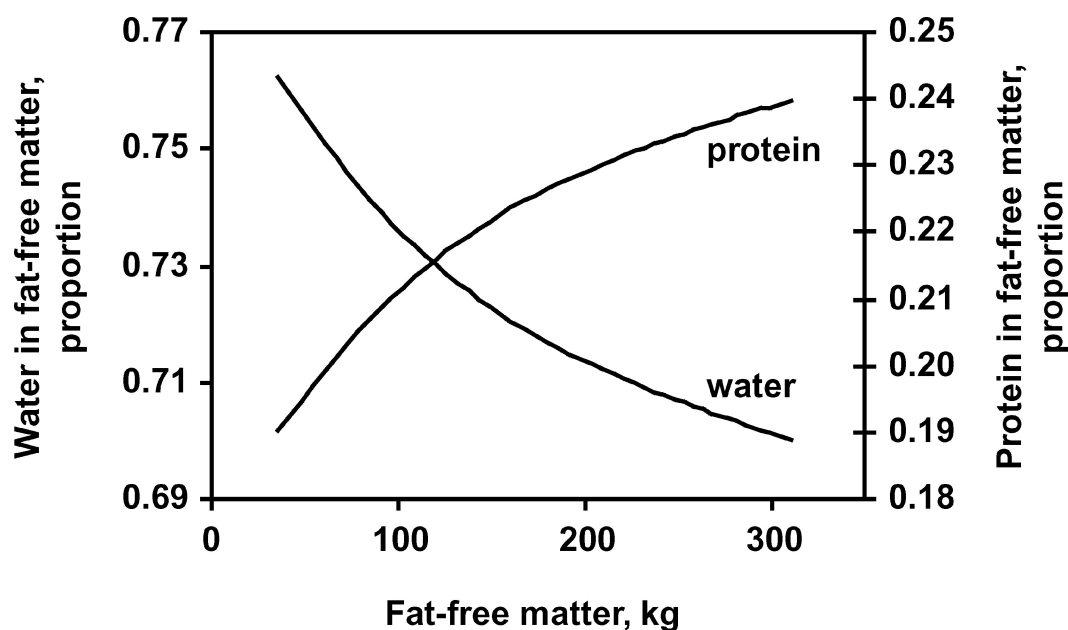
Figure 3. Relationship between the predicted fraction of water and protein in empty body fat-free matter and empty body fat-free matter weight for Hereford × Angus steers in the first three cycles of the Germplasm Evaluation project.
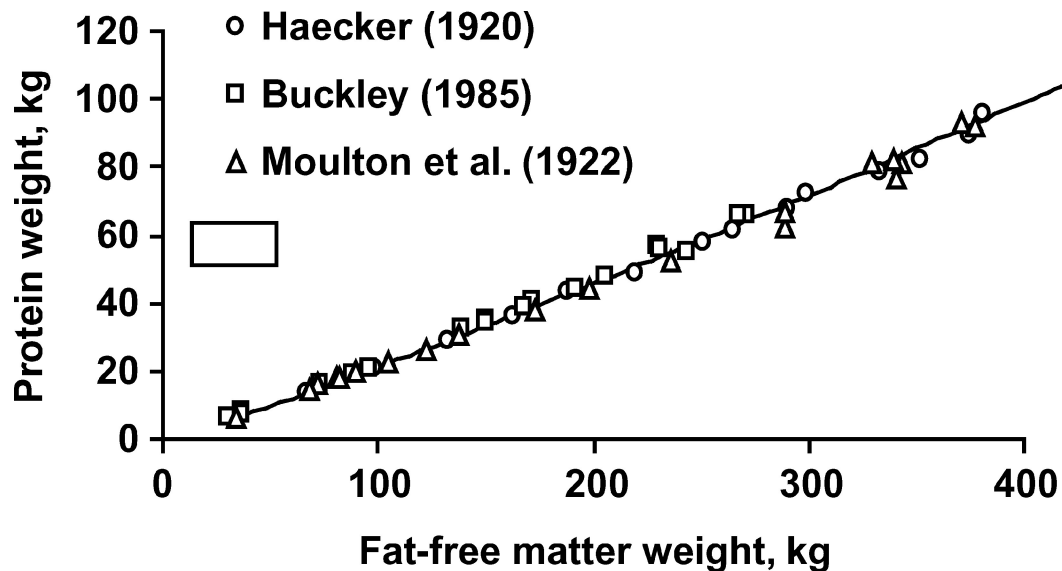
Figure 4. Observed and predicted relationship between empty body protein weight and empty body fat-free matter weight for Hereford × Angus steers in the first three cycles of the Germplasm Evaluation project. Observed data were obtained from published reports by Haecker (1920), Moulton et al. (1922), and Buckley (1985). The continuous solid line represents predicted values for empty body protein weight that were obtained with the model developed in this study.

dEBW from ME that is available for gain and then predicts the composition of dEBW in terms of FAT and FFM. Therefore, with this model, the only unknown in Eq. [1] and [2] is ϕ. The parameter ϕ was estimated by simulating growth and body composition of steers on the high feeding level in the study of Moulton et al. (1922). In this simulation, the value of ϕ was increased from 1.0 to 4.0 in increments of 0.1 in separate runs, and the value of ϕ that minimized the sum of squared residuals between observed and predicted weights of protein was used as the value of this parameter. Composition of dFFM/dt was predicted by first predicting dPRO/dt as $\lambda \times$ dFFM/dt and calculating ash as 0.246 $\times$ dPRO/dt (Reid et al., 1955). Water was obtained as a residual.

The model was evaluated by using the model of Williams and Jenkins (2003a,b) to simulate the growth and body composition from birth to 500 kg BW for Hereford $\times$ Angus steers in the first three cycles of the Germplasm Evaluation (**GPE**) project at the Roman L. Hruska U.S. Meat Animal Research Center. In this simulation, the experimental growth data were used as the inputs to force the simulated animals to grow at the observed growth rate, and the model developed in this study was used to predict the composition of FFM on a daily basis. The model accuracy was tested by comparing simulated protein weight at different stages of growth to observed data from Haecker (1920), Moulton et al. (1922; steers on medium and low nutrition), and Buckley (1985). Linear regression was calculated between observed (y) and

Table 1. Observed (Ferrell and Jenkins, 1998) and predicted data for empty BW of steers on high and low planes of nutrition

Final empty BW, kg[a]	Sire breeds				
	Hereford	Angus	Boran	Brahman	Tuli
Observed					
High	474	498	414	477	420
Low	331	372	328	335	311
Predicted A					
High	465	488	411	478	430
Low	324	366	317	321	298
Predicted B					
High	468	491	415	481	431
Low	331	372	324	327	303

[a]Predicted A was obtained using a constant value of 0.243 for λ (fraction of protein in fat-free matter). Predicted B was obtained using λ values predicted with the model developed in this study.

predicted (x) protein weights, allowing the intercept to be calculated, and then in a second analysis, the intercept was forced through the origin. When the regression is forced through the origin, the SE of the y estimate ($S_{y.x}$) is an estimate of the precision of the predicted values over the range of observations, and the regression coefficient is an estimate of the bias. The model also was evaluated by simulating the growth and composition of steers in data from Ferrell and Jenkins (1998), using the model of Williams and Jenkins (2003a,b) with a constant value of 0.243 for λ in one run, and then using λ values predicted with the model developed in this study in a second run. Simulated results for ending empty BW from both runs were compared with the experimental data.

Results and Discussion

The value for the parameter ϕ that minimized the residual sums of squares between predicted and observed protein weight in the data of Moulton et al. (1922) for Group I steers was 3.0. Predicted responses for the fraction of water in FFM and fraction of protein in FFM for the simulation run with a value of 3.0 for ϕ are plotted in Figure 3 against FFM weight. These predicted responses were very similar to responses observed in data from Haecker (1920) and Buckley (1985), as shown in Figures 1 and 2.

Predicted data for Hereford × Angus steers in the first three cycles of the GPE project show a curvilinear relationship between protein weight and FFM weight in Figure 4. At FFM weights of 35, 237, and 378 kg in the predicted data, the fractions of protein in FFM were 0.190, 0.233, and 0.246. Observed data from Haecker (1920), Moulton et al. (1922; Group II and III steers), and Buckley (1985), also plotted in Figure 4, show a close relationship with the predicted data. At mean observed FFM weights of 33, 235, and 376 kg, for three, six, and five observations at the beginning, middle, and end of the FFM range, the observed fractions of protein in FFM were 0.204, 0.233, and 0.246. These fractions are almost the same as the predicted data and support the curvilinearity of the predicted response. The R^2 for the regression of observed on predicted protein weight was 0.99%. The $S_{y.x}$ of predicted vs. observed protein weight was 1.87 kg and the model underpredicted pro-

tein weight, with a bias of 0.64%. Simulated results for the experiment of Ferrell and Jenkins (1998) are compared with observed data on EBW at slaughter in Table 1. These results show that the model for λ provided a more accurate prediction of EBW than using a constant λ value. These evaluation results suggest that the model can more accurately represent the actual system.

Evaluation of the model showed that it provided accurate predictions of protein gain and that these predictions were more accurate than using a constant fraction of protein in FFM gain. The integral form of the model can be used statically to provide predictions of the average protein gain over a feeding interval. The derivative form of the model can be used in dynamic systems models to provide predictions of daily protein gain.

Literature Cited

Buckley, B. A. 1985. Relationship of body composition and fasting heat production in three biological types of growing beef heifers. Ph.D. Diss., Univ. of Nebraska, Lincoln.

Ellenberger, H. B., J. A. Newlander, and C. H. Jones. 1950. Composition of the bodies of dairy cattle. Vermont Agric. Exp. Stn. Bull. 558.

Ferrell, C. L., and T. G. Jenkins. 1998. Body composition and energy utilization by steers of diverse genotypes fed a high-concentrate diet during the finishing period: II. Angus, Boran, Brahman, Hereford, and Tuli sires. J. Anim. Sci. 76:647–657.

Haecker, T. L. 1920. Investigations in beef production. Minnesota Agric. Exp. Stn. Bull. 193.

Moulton, C. R. 1923. Age and chemical development in mammals. J. Biol. Chem. 57:79–97.

Moulton, C. R., P. F. Trowbridge, and L. D. Haigh. 1922. Studies in animal nutrition III. Changes in chemical composition on different planes of nutrition. Missouri Agric. Exp. Stn. Bull. 55.

Murray, J. A. 1919. Meat production. J. Agric. Sci. (Camb.) 9:174–181.

Murray, J. A. 1922. The chemical composition of animal bodies. J. Agric. Sci. (Camb.) 12:103–110.

Reid, J. T., G. H. Wellington, and H. O. Dunn. 1955. Some relationships among the major chemical components of the bovine body and their application to nutritional investigations. J. Dairy Sci. 38:1344–1359.

Williams, C. B., and T. G. Jenkins. 2003a. A dynamic model of metabolizable energy utilization in growing and mature cattle. I. Metabolizable energy utilization for maintenance and support metabolism. J. Anim Sci. 81:1371–1381.

Williams, C. B., and T. G. Jenkins. 2003b. A dynamic model of metabolizable energy utilization in growing and mature cattle. II. Metabolizable energy utilization for gain. J. Anim. Sci. 81:1382–1389.